CHAPTER 8

CONCLUSIONS

Current friction materials used for brake-pads, linings, shoes, blocks and clutch facings are based on very complex formulations containing ingredients of various types, natures and in various combinations and amounts. The influence of these ingredients on performance properties is so complex that formulation of friction materials is still referred as an art rather than science. Among the various properties, a brake pad is supposed to fulfil, resistance to fade and resistance to wear is difficult to achieve.

The organic components normally tend to burn off causing fade. Hence, in this work, the effect of the organic ingredients namely binder (Alkyl Benzene modified phenolic resin), organic friction modifier (cashew friction dust) and organic fibers (Aramid, Acrylic and Cellulose) with respect to fade and wear was studied and the following observations were made.

In the first part, three brake pads were made with three resins with varying molecular weight. Tests were conducted to discuss an experimental study that considers the effect of molecular weight of the resin in relation to fade and wear of a non asbestos disc brake pad and the following conclusions were drawn:

By altering the molecular weight, the properties such as, flow distance, gel time and hexa content of resin also changed. As the molecular weight increased, the melting point increased. This increase in melting point
increased the degradation temperature of the resin. As the molecular weight increased, the flow distance increased, which made the resin to flow easily and hence quicker was the cross linking thereby increasing the binding force. This in turn increased the rigidity of the pad which showed poor resilience as noticed by the shear strength value. Faster cross linking reduced the gel time, which shortens the moulding time as noticed in the acetone extraction which is good for increasing the productivity.

Brake pads made of resin with lower molecular weight FCL ($M_w = 2412$) showed excellent fade resistance. It has 20% greater fade resistance than pads made with medium molecular weight FCM ($M_w = 4544$) and 50% greater than pads made with higher molecular weight FCH ($M_w = 5223$). The reason being mobility of the low molecular weight resin is higher resulting in the easier plastic deformation, which leads to a larger contact area and hence the friction value increases. Hence, under moderate operating conditions ($344^\circ C$) the lower molecular weight chain enhanced the $\mu$. The recovery characteristics of pad with this resin are very poor. One of the reasons may be due to its degradation temperature ($328^\circ C$) well below the maximum temperature recorded ($344^\circ C$) before the start of the recovery cycle.

Brake pads made of resin with higher molecular weight FCH ($M_w = 5223$) showed poorer fade resistance. But it has 25% greater recovery than pads made with lower molecular weight FCL ($M_w = 2412$) and 1.2% greater recovery than pads made with medium molecular weight FCM ($M_w = 4544$). The fade resistance is poorer as the mobility of the higher molecular weight resin is lower making the pad to be more rigid, which reduces the real area of contact and hence the friction value decreases. Brake pads made of resin with a molecular weight ($M_w = 4544$) FCM showed the consistent friction level throughout the testing as per SAE J661 standards. Hence, resin with molecular weight FCM ($M_w = 4544$) is considered suitable for further study.
However, no significant difference was noted in the wear pattern in all the three brake pads.

After selecting the resin type, that is resin with the molecular weight \( M_w = 4544 \), optimization was carried out for best performance of tribological properties by varying the resin content alone, which is compensated by the inert filler barytes in the formulation and it is observed that:

- With the increase in resin content, hardness of the brake pads decreased. Porosity decreased with the increasing resin content. This is because the resin flows through gaps in the friction material during hot pressing and fills voids (Ho Jang 2007) before it is consolidated during curing. The increase of resin content helped to strengthen the interface bonding between the reinforced fibres and the resin matrix which in turn slightly improved the shear strength. From TGA studies, it is observed that the thermal stability of the friction materials decreased with the increase of the resin content as observed from more weight loss in the second stage of degradation in all the three TGA curves.

- Brake pads made with 10.11% resin content DBL has 20% higher fade resistance than pads made with 11.11% DBM and 41% higher fade resistance than the pads made with 12.11% resin DBH. The reason is due to the high temperature recorded during the fade test which is above the degradation temperature of the resin. Higher the resin content, the higher was the degradation and the binding force gets weakened further which causes the change in real contacts at the friction interface and hence \( \mu \) falls down.
- Brake pads made with 10.11% resin DBL have 18% quicker recovery than pads made with higher amounts of resin DBH and 26% more than pads made with 11.11% of resin DBM. Higher the resin content, higher was the temperature rise in the disc and this pattern followed uniformly for varying content of resin. In spite of higher thermal stability, higher hardness and good fade resistance pads made with lower resin content 10.11% DBL have poor wear resistance and the trend was exactly opposite for the pads made with 12.11% of resin content DBH. There were no clear correlations between either friction or wear and the thermal stability of the resins or the mechanical properties of the brake pads.

- Scanning electron microscopy revealed that resin with higher amount of resin content formed more amounts of secondary plateaus (Nidhi 2007) which were observed on the surface. The micrographs of the worn surface show that the wear of the sample was taken place by combination of three mechanisms: (i) adhesion, (ii) abrasion and (iii) delamination. Since safety comes to top priority, DBL was found to be superior in most of the important tribological and strength related properties.

Another organic ingredient, namely cashew friction dust is varied along with the selected Alkyl benzene modified phenolic resin with the molecular weight ($M_w = 4544$). Regression analysis was also carried out to check for the most dominating factor which controls the $\mu$, and the following conclusions were drawn:

- All the brake pads showed sufficient $\mu$ (0.30-0.45), which is in the desired range as per the industrial practice. The friction coefficient decreased with speed and pressure in general for all the brake pads.
Decreasing the amount of resin and friction dust led to an appreciable increase in magnitude of $\mu$ and stability of friction. Fade testing of all composites tested resulted in a temperature rise in disc higher than the decomposition of the resin. Only in the case of BPH, the temperature rise in fading exceeded the decomposition temperature of friction dust.

- Based on the regression analysis, it was concluded that the major influences on $\mu$ were due to the material itself followed by first order contributions from the speed. Speed was observed to be a more dominant parameter, which influenced the $\mu$ rather than the pressure.

- Response surface methodology indicates the optimum percentage of resin and friction dust to a loading level of 10.11 by weight percentage of resin and 9.33 by weight percentage of friction dust (BPL) which gives the desired level of friction coupled with the lower amount of wear. The same formulation was remolded. Tribological properties evaluated confirm the RSM results. Hence, this optimum level of organic contents, 10.11 wt% of resin and 9.33 wt% of friction dust (BPL) tends to stabilize $\mu$ and hence improve the overall performance of the composites.

Another organic ingredient, namely organic fibers (Aramid, Acrylic and cellulose) were varied in a Non Asbestos organic brake pad formulation to study its effect on fade and wear. Based on the studies conducted on composites with increase in organic fiber contents it is observed that increase in organic fiber content reduced the hardness and specific gravity. Increase in fiber content also leads to increase in $\mu$ value as found in the composite with a higher percentage of fibers. In case of TGA and DTG studies, the % weight loss in brake pad with higher amount of fiber is less compared to other two compositions which indicate higher thermal stability. Hence, the thermal
stability could be correlated with the friction stability. Higher the thermal stability, higher was the friction stability. The wear rate is also lower than the other two composites due to more amount of plateau formation as noticed from the SEM images.

It is interesting to observe that while the resin content is increased during the optimization of resin, the thermal stability decreased. The reason is due to the higher temperature to which the resin is exposed, during the TGA studies, where it gets degraded. But during the optimization of organic fibers, it is found that increase in amount of organic fibers increased the thermal stability. In spite of poor resistance to heat by cellulose and acrylic fibers, their combination with the aramid fibers increased the thermal stability. The degradation mechanism of brake pads with more amounts of ingredients is still a complex phenomenon to understand clearly. Hence, it is observed that the effect of different organic ingredients functions differently.

Overall, the influence of the organic ingredients namely the Alkyl benzene modified phenolic resin, organic friction modifier and organic fibers were studied with respect to thermo-physical and tribo-properties of Non asbestos disc brake pad. Since the formulations are checked as per the Industrial standards of original equipment manufacturing, the final step is on road testing, which will reveal the real performance of the brake pads which has to be carried out in the future after getting the required permissions from the Government regulations body. After discussing with the Industrial people, it was understood that the cost of O.E pad mix per kg will be kept within Rs.100/- The cost of the mix per kg of the developed formulation is around Rs.120 which is slightly higher and has to be taken care of. All the developed formulations thus exhibit a great potential for commercial applications, especially for light commercial vehicles.
RECOMMENDATION FOR FUTURE WORK

- Since the formulations are checked as per the Industrial standards of original equipment manufacturing, the final step is on road testing, which will reveal the real performance of the brake pads which has to be carried out in the future after getting the required permissions from the Government regulations body.

- Also an Indian patent of formulation for development of Non asbestos, Low copper friction material for Automotive disc brake pads was filed as copper was banned by the Environmental regulatory authority.

- Other major issues related to braking like vibration and noise has to be dealt with.